AD-A047 413 NAVAL RESEARCH LAB WASHINGTON D C F/G 14/5

CHARACTERISTICS OF SOME 35-MM FILMS FOR HOLOGRAPHY AT 694.3 NM.(U)

SEP 77 R L EASTON, J A BLODGETT

UNCLASSIFIED NRL-8142 SBIE-AD-E000044 NL

1 OF 1

AD A047413

END

DATE FILMED

1 -78

DDC

NRL Report 8142

Characteristics of Some 35-mm Films for Holography at 694.3 nm

R. L. EASTON, JR., AND J. A. BLODGETT

Applied Optics Branch
Optical Sciences Division

September 12, 1977

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (14) NRL [redacted] 8142	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) CHARACTERISTICS OF SOME 35-mm FILMS FOR HOLOGRAPHY AT 694.3 nm,		5. TYPE OF REPORT & PERIOD COVERED (9) Interim report on a continuing NRL Problem.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) R. L. Easton, Jr. [redacted] J. A. Blodgett		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D. C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem N01-16.104 Project RR 011-07-41
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Research Laboratory Washington, D. C. 20375	(11) 12	12. REPORT DATE Sep[redacted]2, 1977
		13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 12p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(16) RR01107 (17) RR0110741

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(18) SBIE (19) AD-E000 044

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Holography
35-mm films

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Measurements of modulation transfer functions, signal-to-noise ratios, and sensitivities have been made for several 35-mm films in preparation for a study of long-distance holographic imaging in Q-switched ruby laser light (694.3 nm).

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251 950

VP

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

CHARACTERISTICS OF SOME 35-mm FILMS FOR HOLOGRAPHY AT 694.3 nm

INTRODUCTION

In preparation for an investigation of long-range holographic imaging, relevant parameters of photographic films were measured in various developers. Transfer characteristic curves in Q-switched ruby laser light (694.3 nm) and modulation transfer functions in the red region (647.1 nm) were plotted. The goal was to select the combination of film and processing most suited for holographic imaging at 694.3 nm in the long-range experiments.

For holography in the laboratory, the desirable characteristics of processed emulsions usually are high contrast, high resolution, high sensitivity, and low film noise. High contrast and low noise ensure a good signal-to-noise ratio in the reconstructed hologram. High sensitivity allows a shorter exposure in the lab, reducing the likelihood of vibrations that may wipe out the interference pattern. In offset reference beam holography, high-resolution films are required to record interference fringes of high spatial frequency, typically 1000 to 4000 line pairs per millimeter (lp/mm).

For long-range lensless Fourier transform holography, film requirements are somewhat different. The desired characteristic of high contrast must be sacrificed to some extent for increased dynamic range. That is, the processed film should be linear in amplitude transmission over a greater spread in incident energy. Normally in laboratory holography, the energy incident on the film is readily measured and repeatable. The films can be selected and processed for high contrast and thus good signal-to-noise ratios.

In long-distance holography through turbulent media, however, the energy of light returning to the film from the target cannot be accurately predicted due to the phase variations of the intervening media. In a fleeting moment of "good seeing," virtually all light in the cone defined by the holographic receiver and the target reference may be incident and uniformly distributed on the film. A short time later, the phase variations in the media may be so severe that large parts of the returning beam may be deviated out of this cone or concentrated in a small part of it. Thus the number of photons incident on a particular part of the film may vary widely from moment to moment depending on atmospheric conditions. Because of this problem, the emulsion used to record the hologram must be linear in amplitude transmission T_A over a wide dynamic range. A study by Deitz [1] indicated values for the required dynamic range at 694.3 nm over various distances for three degrees of turbulence (three values of the index structure coefficient C_n). Over a 1-km path, dynamic ranges of about 20 dB are typically required, with greater range necessary in conditions of more severe turbulence.

The other characteristics of films for laboratory holography are desirable for long-distance holography as well, though not always for the same reason, and the requirement for high resolution is greatly relaxed. High sensitivity is necessary because the energy incident on the film is limited by the output of the laser and the aperture of the receiver. The resolution of the film is important because it determines the field of view that is

Manuscript submitted June 7, 1977.

imaged. In making the hologram, the interference fringes are formed on the aperture of the receiver, and are thence imaged onto the film by the camera lens. For the telescope and camera lens employed, the interference pattern is photographically reduced from 355 mm in diameter to about 10 mm. This represents an increase in fringe spatial frequency by a factor of about 35. If the film can resolve 35 lp/mm, then it can record a spatial frequency on the aperture of the receiver of 1 lp/mm. This frequency can be related to the size of the target that can be imaged by

$$\frac{\lambda}{d} L \approx D.$$

where

λ = 694.3 nm, laser wavelength

d = fringe spacing at aperture ($\approx$ 1 mm)

L = distance to target, 1 km

D = maximum linear extent imaged.

For these conditions, $D \approx 0.7$ m.

For a film of higher resolution, the fringe spacing d decreases and D increases. Thus a film of higher resolution increases the field of view.

FILMS AND PROCESSING

The films selected for testing were chosen with the above characteristics in mind, along with consideration of sensitivity in the far-red visual spectrum and availability in the 35-mm format. Most films considered fall off rapidly in sensitivity for wavelengths longer than about 650 nm. Eastman Kodak produces a selection of data recording films whose sensitivities remain relatively constant to about 700 nm. Preliminary testing of film sensitivity was carried out on Kodak 2476 Linagraph Shellburst film, Kodak 2475 recording film, Kodak 2479 RAR film, Kodak 2485 HSR film, Kodak 2496 RAR film, Kodak Plus-X Aerecon film 8401, Kodak Plus-X Aerographic film 2402, Kodak Tri-X Aerographic film 2403, and Kodak Photomicrography Monochrome film SO-410. From this list, the films 2476, 2496, and SO-410 were selected for more exhaustive tests. Only the first two of these showed adequate sensitivity and resolution for potential use in the experiment, but the SO-410 was chosen also because of its high resolution. All three are available in the 35-mm format required by the motorized cameras available for use in the experiment.

In processing, several high-contrast developers were tested, including Kodak D-19, D-76, and HC-110. For lower contrasts, one metol-based and two phenidone-based developers were tested. One of the phenidone developers, POTA, has been described and tested by Marilyn Levy [2]. The metol developer was described by Shulman [3]. The developers are listed in Table 1. Uniform conditions in processing were ensured by mechanical agitation and temperature checks. After development, films were fixed, washed, and dried in the manner described in the data sheets for that emulsion.

Table 1 — Developers

Developer		Conditions
Kodak D-19		8 min at 20°C
Kodak D-76		8 min, 5 min at 20°C
Kodak HC-110		Dilutions D(1:9), E(1:11), 8 min at 20°C
POTA —		5 min at 35°C or 10 min at 20°C
1-Phenyl-3-pyrazolidone (phenidone);	1.5 g;	
Sodium sulfate,	30 g;	
Water to make	1 l	
Metol-Based —		5 min at 20°C
Metol,	2 g;	
Sodium sulfate (anhydrous),	10 g;	
Sodium carbonate (anhydrous),	10 g;	
Potassium bromide,	0.5 g;	
Water to make	1 l	
Phenidone-Hydroquinone —		5 min at 20°C
Phenidone,	0.4 g;	
Hydroquinone,	10 g;	
Sodium sulfite (Anhydrous),	100 g;	
Amenoacetic acid	10 g;	
Sodium borate,	3 g;	
Boric acid,	3.5 g;	
Potassium bromide,	1 g;	
Water to make	1 l	

TRANSFER CHARACTERISTICS

In conventional photography, the emulsion parameters of interest are indicated on the H-D curve, (density vs log exposure). In coherent imaging, on the other hand, the relevant characteristics are shown on the T_A vs E curve (amplitude transmission vs exposure). This is because coherent imaging systems are linear in amplitude, rather than in intensity. In addition, the extremely short duration of the Q-switched laser pulse ($\tau < 50$ ns) results in reciprocity-law failure. Transfer characteristics determined under other than Q-switched conditions may not be extrapolated to these much shorter exposure times.

For the tests, the films were cut into 25-cm strips and overlaid with a calibrated Kodak No. 3 photographic step tablet, with 21 density steps. One long edge of each strip was not covered by the step tablet to allow determination of exposure uniformity. The strips were exposed by light from a Korad Q-switched ruby laser located 25 m from the film holder. The light was diffused by a large ground glass screen located 4 m from the film holder. The light energy incident on the film was monitored by a detector incorporating an E.G.&G. SGD-100 photodiode. This detector was calibrated before and after these tests. With the known densities of the step tablet, the incident energy on each segment of the film strip is easily found.

After exposure, the strips were processed in the various chemicals, and density measurements were made on a Leeds and Northrop microdensitometer. Density values were converted to amplitude transmissions via $T_A = 10^{-D/2}$. From these data, the $T_A - E$ curves were plotted, allowing determination of exposure ranges for each film and developer resulting in linear response.

From the $T_A - E$ curves (Figs. 1-3) it is seen that Kodak 2496 is the most sensitive when a high-contrast developer like D-19 is used. For lower contrast developers, specifically D-76, 2476 is faster and more linear than 2496. From the curves, the very low contrast nature of POTA is quite visible. Kodak SO-410 is seen to be much slower than either 2496 or 2476, but it is also more linear than either when processed in medium-contrast developers.

On the basis of these data, and considering the energy available over the 1-km distance to the target, Kodak 2476 in D-76 was chosen as the film — developer combination.

MODULATION TRANSFER FUNCTIONS

A technique developed by Goodman and Lehmann [4] was used to measure the MTFs of the films. Holograms were made of a test object consisting of a number of evenly spaced, diffusely illuminated small holes. Sixteen holes of 1-mm diameter were drilled on 1-cm centers in an aluminum strip. A translucent mylar sheet was applied to the rear of the holes to diffuse the illumination. The spatially filtered reference beam was located 2 cm to one side and slightly above the object holes. The vertical displacement of the reference beam prevented interference by higher-order reconstructions in the intensity measurements. In the experimental setup (Fig. 4), spatial frequencies at the film plane ranged from 25 lp/mm, for the object hole closest to the reference, to 230 lp/mm, for the most distant object hole. For these tests, film exposure by the ruby laser was deemed impractical, and so a Spectra-Physics krypton ion laser operating at 647.1 nm was substituted.

Steps were taken to make the object-hole illumination as uniform as possible, primarily by diffusion of a greatly expanded beam by a large ground glass, followed by a matte white cubic "integrating sphere." These efforts resulted in a significant improvement in the uniformity of illumination, though the variation in intensity across the field of object holes was still 50%. The variation was taken into account in the intensity measurements of the reconstructed images.

To ensure that variations in the intensity of the reconstructed images were not due in part to differences in path length in the recording geometry, the laser was operated with an etalon as longitudinal mode selector. The coherence length of the laser is greater than 1 m, while path differences were of the order of 10 cm.

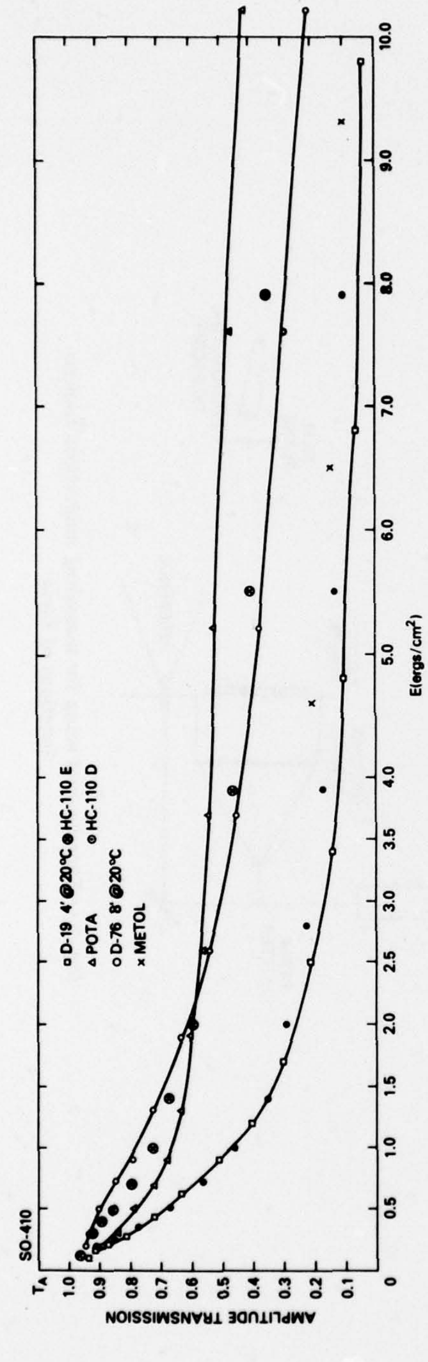

Fig. 1 — T_A vs E curves for Kodak 2496 RAR film

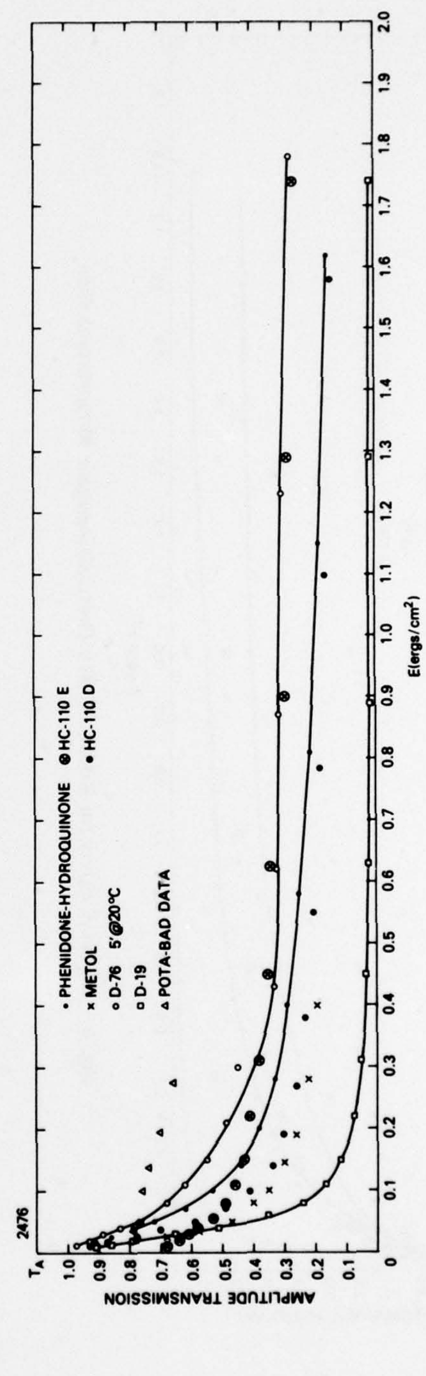

Fig. 2 — T_A vs E curves for Kodak Linagraph Shellburst film

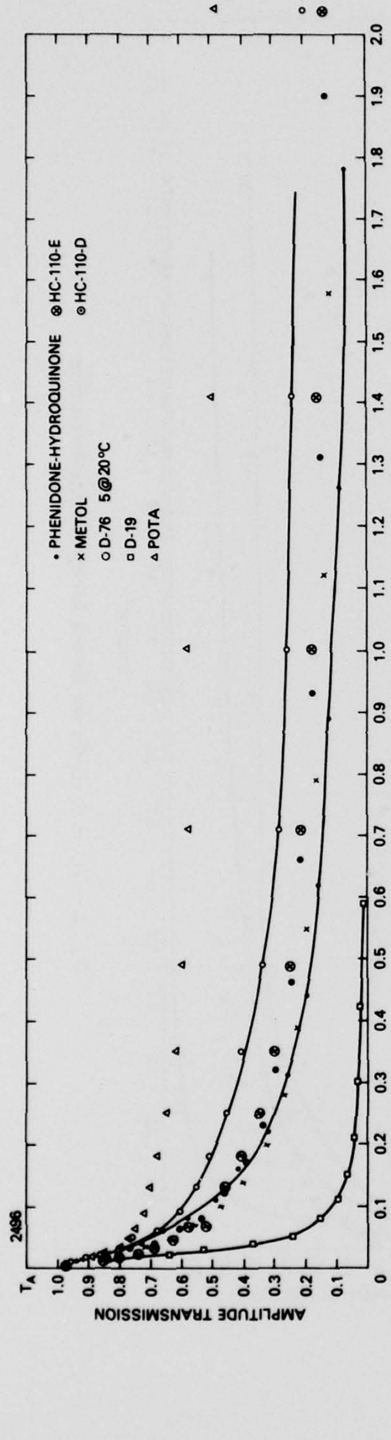

Fig. 3 — T_A vs E curves for Kodak SO-410 Photomicrographic Monochrome film

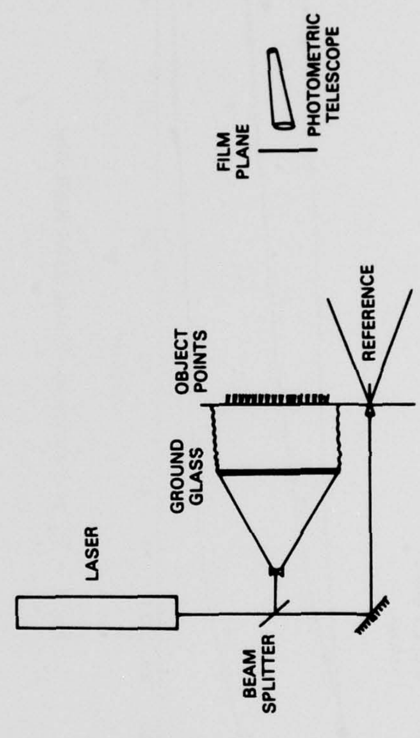

Fig. 4 — Experimental setup for measuring modulation transfer functions of films

A Gamma Scientific 2020 photometric telescope was used with a fiber-optic probe and photomultiplier detector to measure the intensities of both the object holes and the reconstructed images. In addition to these data, measurements were made of the reconstructed hologram of points midway between the object holes. This provides an indication of the magnitude of noise due to light scattered by the emulsion grains in the hologram.

Holograms of this test object were made with reference-to-object beam ratios of approximately 16:1, 32:1, and 128:1, to simulate possible situations in the long-range experiment. After processing, frames of approximately 0.6 density were selected for reconstruction. After measurements of the intensity of each hole and noise intensity in the reconstructions were made, the data for each film was plotted as normalized intensity (intensity of first hole = 1) vs spatial frequency. Some typical results are shown in Figs. 5-9. As expected, SO-410 showed a much better reconstruction with much less noise. Also, in general, Kodak 2496 had better resolution than Kodak 2476, though the 50% intensity of reconstruction for both was about 40-50 lp/mm.

CONCLUSIONS

As previously mentioned, Deitz [1] has shown that scintillation in a ruby laser beam over 1 km requires the imaging detector to have a dynamic range of about 20 dB for moderate turbulence. None of these films can satisfy that requirement. With the energy available over a 1-km path with a 1-J ruby laser, Kodak 2476 processed in D-76 for 5 min is approximately linear in amplitude transmission down to 0.4 erg/cm^2, providing a dynamic range of 13 dB or less. The modulation transfer function shows that the 50% modulation point for Kodak 2476 is at about 50 lp/mm, adequate to reconstruct points on the target located about 0.8 m from the reference point over a 1-km path.

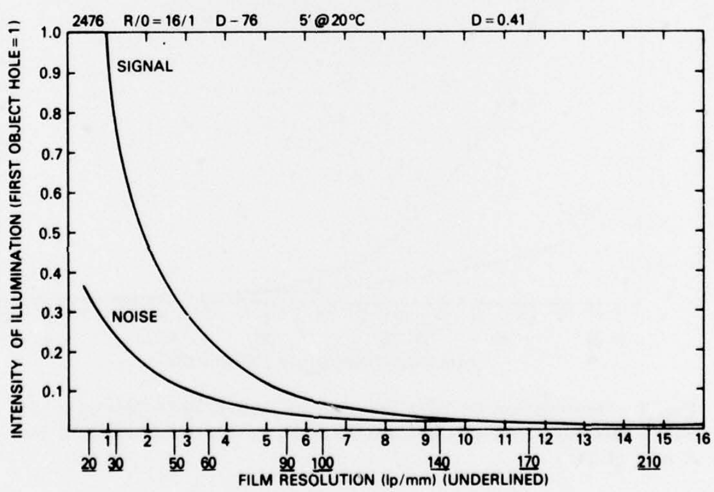

Fig. 5 — Modulation transfer function of Kodak 2476 film exposed with a reference-to-object beam ratio of 16:1. Processed in D-76 for 5 min at 20°C.

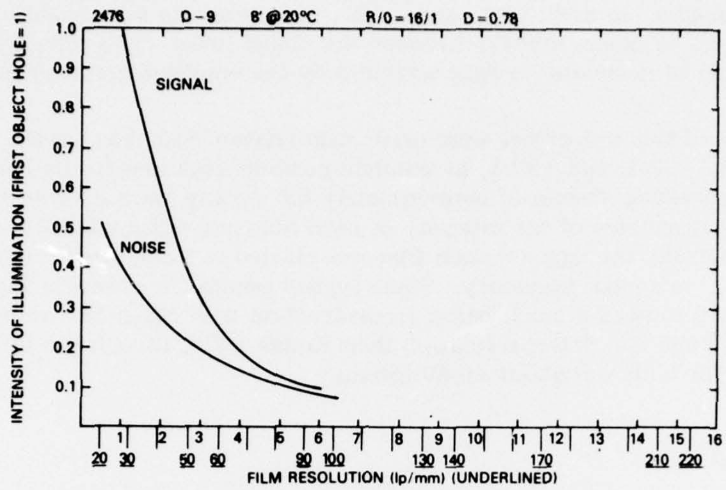

Fig. 6 — Modulation transfer function of Kodak 2476 film exposed with a reference-to-object beam ratio of 16:1. Processed in D-19 for 8 min at 20°C.

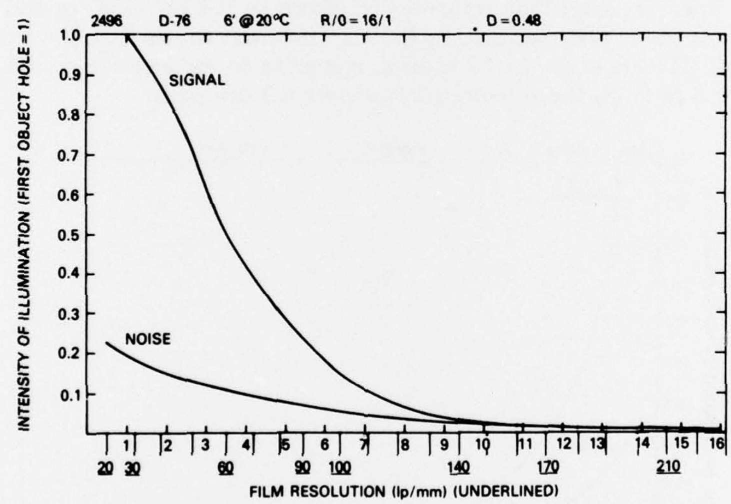

Fig. 7 — Modulation transfer function of Kodak 2476 film exposed with a reference-to-object beam ratio of 16:1. Processed in D-76 for 6 min at 20°C.

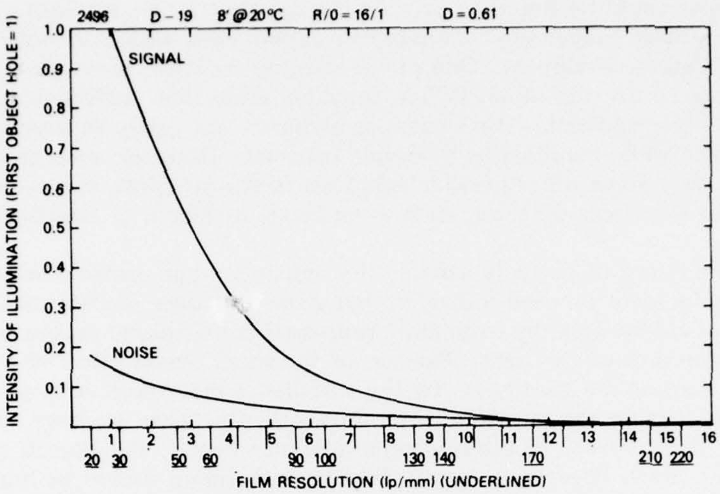

Fig. 8 — Modulation transfer function of Kodak 2476 film exposed with a reference-to-object beam ratio of 16:1. Processed in D-19 for 8 min at 20°C.

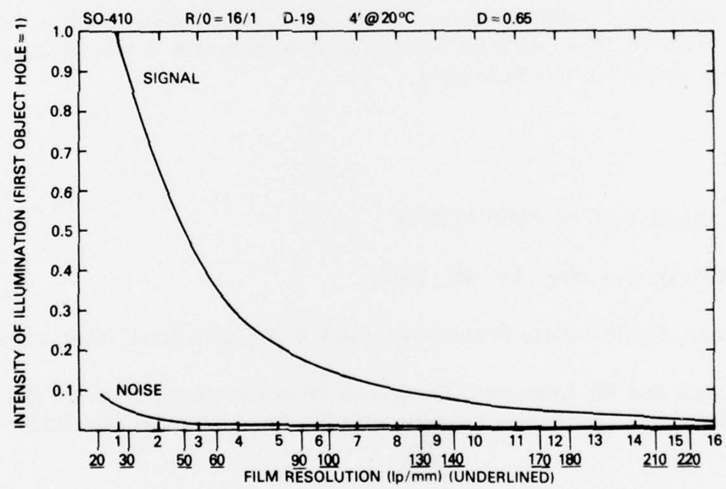

Fig. 9 — Modulation transfer function of Kodak 2476 film exposed with a reference-to-object beam ratio of 16:1. Processed in D-19 for 4 min at 20°C.

The intent of this investigation was to determine if an appropriate combination of film and developer could be found to provide the dynamic range, resolution, and contrast required for long-range holography. Goodman's experiments were conducted with only one film and two different developers. One of the developers, HRP, provided a linear dynamic range of less than 10 dB; the other, POTA, provided more than sufficient dynamic range but at extremely low contrast. The current experiment was partly successful in extending the dynamic range while maintaining moderate contrast. However, even greater range would be desirable. Some other possible solutions to this problem, suggested by Goodman, are the use of an electronic detector, such as an image orthicon, or multilayer emulsions.

A possible method of partially skirting the dynamic range problem would be to estimate the energy incident on each individual hologram and then process each for optimum contrast. This could be done by examining processed conventional images of the target taken on the same shot of the laser. Because of the small cross-section of the retroreflector ($\approx 1\ cm^2$), breakup of the laser beam by the turbulence may result in large variations of the intensity incident on the retroreflector. Consequently, there are large variations, from shot to shot, in the intensity of the returning reference beam. The object, on the other hand, is normally much larger in area, and thus beam breakup should be much less significant with respect to the intensity of the returning object beam.

The apparent size of the reference beam seen in the conventional image could be used as an indication of the energy of the beam. If it is seen to be quite intense, the hologram could be processed in a very low-contrast developer. For a less intense reference beam, a higher-contrast developer might improve the signal-to-noise ratio. Such a technique would be much more involved than using an electronic detector, and it would not overcome problems due to "hot spots" in the hologram.

REFERENCES

1. P. H. Deitz, *Appl. Opt.* 8, 2293 (1969).

2. M. Levy, *Photogr. Sci. Eng.* 11, 46 (1967).

3. A. R. Shulman, *Optical Data Processing*, John Wiley and Sons, New York, 1970.

4. J. W. Goodman and M. Lehmann, *Detection Processes for Wavefront Reconstruction Receivers*, Stanford Electronics Laboratories Technical Report No. 2311-1, 1967.